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Technical Lesson 32

PRACTICAL CONSIDERATIONS FOR THE DESIGN OF SCREEN-GRID RECEIVERS

The popularity achieved by the new electrically operated screen-grid receivers is a tribute to those who are responsible for the production of the a-c screen-grid vacuum tube. When the wonderful characteristics which this tube possesses became known the interest of radio set manufacturers centered chiefly around the development of an electric set that could utilize one or more of these tubes and obtain from them every advantage to the fullest extent. Although the tube was originally designed to reduce inter-electrode capacity to a negligible amount and thus make it possible to build radio-frequency circuits without requiring the use of neutralizing devices of any kind, yet it was soon noticed that the tube had extraordinary amplifying qualities. To think that the amplification constant of an a-c screen-grid tube is 420 as compared to 9 for the three-electrode tube is nothing less than remarkable. Weak signals or signals from distant stations are amplified many fold to be reproduced by the loudspeaker with ample volume, and the signals from nearby local stations usually come in with such large amounts of power that a volume control is required ahead of the detector so that the signal voltage applied to the detector grid may be lowered to a suitable value to prevent detector overloading. An overloaded detector produces distortion no matter what efforts are made to overcome this condition through careful designing of the audio amplifier circuits. The extra high gain of signal level in a receiver using two stages of tuned radio-frequency amplification and a-c screen-grid tubes requires that some method of lowering this level be incorporated in the antenna input circuit. Thus, we have what is known as a "LOCAL-DISTANT" switch which is brought into operation under extreme conditions, that is, where a strong local signal would cause detector overloading. Although the use of the "LOCAL-DISTANT" switch and the volume control both have the same ultimate effect of controlling volume by permitting more or less signal energy to be applied to the detector grid, yet the principles upon which they operate are by no means identical as we will explain further in our lesson.

While on this subject of screen-grid receivers attention should be called to the fact that other models of receivers employing three-electrode tubes (for instance, the 227 or 226 type) as radio-frequency amplifiers, and with the r-f stages properly neutralized, give results which compare favorably with those obtained from screen-grid sets. The set which does not use screen-grid tubes, however, will invariably be supplied with an additional radio-frequency tube thus permitting it to reach the higher degree of sensitivity. What we wish to point out is that the type of tube, or the number of stages of radio-frequency amplification incorporated in the design of a receiver is not a basis for estimating the performance of the set. We must realize that although the figures mentioned in the preceding

paragraph comparing the amplification constant of two different types of tubes are at such a wide variance these figures do not express in any sense the relative gain in radio-frequency amplification to be expected between the two tubes under consideration when operating in particular receiving circuits. The true gain in signal energy from any receiving circuit can be found only by measuring the performance under practical conditions and not by computing the gain from figures based on tube characteristics.

Whether one type of tube or another is more effective as an amplifier depends as much upon the circuit design and quality of the parts as upon the tube itself. Up to the present time not anything near the gain of which a screen-grid tube is theoretically capable has ever been fulfilled. For example, the advent of the screen-grid tube has brought about special considerations in the matter of coil design to reduce capacity effects and give the plate circuit a high impedance at resonance, and even with the best designing the impedance of the load circuit, due principally to the coils, is still far below the tube's plate impedance which is several hundred thousand ohms. These and other factors which govern the maximum gain possible from screen-grid amplifiers (referred to usually as sensitivity) and also the degree of sharpness of tuning that permits a receiver to cut through a strong local station and pick up a distant station when both are working on closely adjoining frequencies (referred to as selectivity) are discussed in the following paragraphs.

So that you may grasp at a glance the various important features in a-c screen-grid receivers which are not found in receivers of other types we have prepared the list given below. In comparing the sensitivity of any two receivers, tube for tube, we assume that in each case the tuned r-f stages are properly designed. The characteristics of the screen-grid set are, briefly:

1. High sensitivity with less tubes.
2. Selectivity greater than that obtainable from a similar number of tuned stages when tubes not of the screen-grid type are used.
3. Ease of control. Screen-grid tubes lend themselves to a very simple means of volume control and due to the fewer number of tuned r-f stages the gang condenser construction is greatly simplified.
4. Freedom from noise. The reduced number of tuned stages permits receivers of the screen-grid type to have a minimum signal to noise ratio.
5. Less adjustments needed. The elimination of a tuned r-f stage means the elimination of a trimmer condenser which would otherwise require careful adjusting to place one stage in resonance with another.

In this lesson we have divided our subject into several sections according to the functions of the principal circuits of an alternating current operated receiver of the type which you are about to construct. This is a seven-tube a-c screen-grid receiver employing two of the screen-grid type 224 tubes, two type 227, two type 245 power amplifiers and one type 280 full-wave rectifier.

Reference to the schematic diagram of any electric set will clearly show that the receiver is divided into two main parts; namely, the "receiver proper" and the "power unit," often called the "power pack." In turn we can subdivide these parts into their principal circuits, each one of which will be treated as a separate topic in our lesson. No doubt most of us are particularly interested in the a-c screen-grid tube for the reason that it is one of the newer contributions to the science of Radio, therefore, our discussion naturally will lean toward the tube itself and the radio-frequency circuit in which it is used. Our lesson is divided into seven topics according to the classified list given immediately below.

(A) The principal circuits of the receiver proper:

1. Radio-frequency amplifier stages.
2. Detector.
3. Audio-amplifier stages.

(B) The principal circuits of the power pack:

4. A-C input and power transformer.
5. Full-wave rectifier.
6. Filter, consisting of choke coils and condensers.
7. Voltage distribution system, consisting of several resistors.

It is suggested that you study this lesson with the idea of keeping the seven principal circuits separated clearly in your mind. Also, learn as much as you can about the principles involved in each circuit so that when you come to the constructional work and assemble the parts and wire them you will have a thorough understanding of the operation of the entire receiver. The schematic diagram of our receiver is shown in Figure 1 and it should be followed closely throughout the explanations.

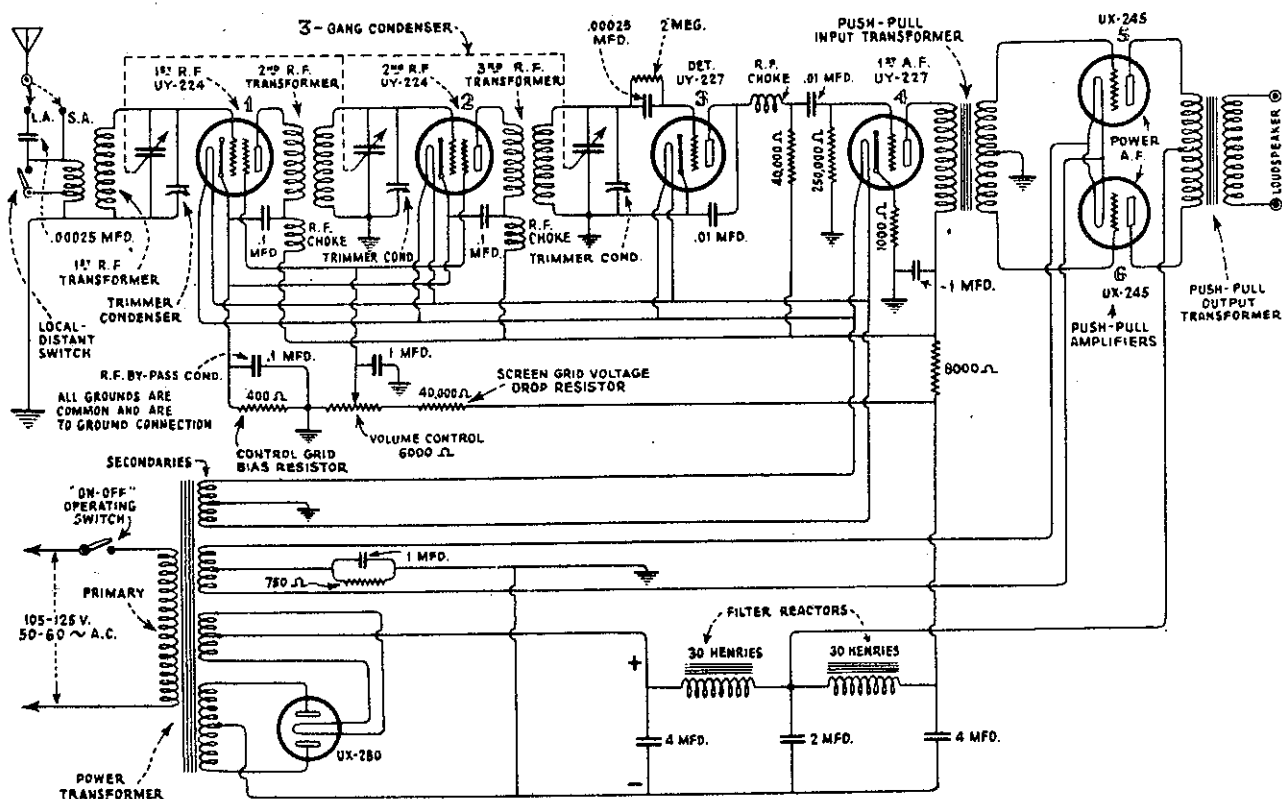


Figure 1

PART 1

RADIO-FREQUENCY AMPLIFIER

The part of the radio receiver using screen-grid vacuum tubes that differs from the conventional type tuned r-f receiver is the radio-frequency amplifier. The radio amplifier in our set employs two UY-224 tubes in two tuned stages, and since the detector grid input circuit is also tuned we actually have three tuning circuits which requires a three-gang condenser. The rotor plates of the variable tuning condensers are mechanically and electrically connected together as indicated on the diagram by the dotted lines and marked at the top "3-gang condenser." Each section of the gang condenser is provided with a small trimmer condenser built in the unit so that a trimmer is shunted across each tuning condenser. This arrangement permits the use of a single dial for simultaneously tuning the r-f circuits, and to most persons this is preferable to independently tuned circuits from the standpoint of convenience in quickly changing from one station to another. The stator plates of the tuning condensers connect respectively to the grids of the 1st and 2nd r-f amplifiers and to the detector, whereas, the rotor plates are all grounded.

The three r-f transformer coils are wound to give them the best transformer characteristics and each one is completely enclosed in an aluminum can which acts as an electrostatic shield to eliminate coupling effects between the coils themselves, or between the coils and other parts of the circuit. Without the shielding cans over the coils the circuits would at once become unstable and readily break into oscillation that could not be controlled. Under such conditions the set would probably be unreceptive at any setting of the tuning dial, or at least it would be found unmanageable on the higher broadcast frequencies.

From the diagram in Figure 1 each tuned circuit is seen to be a conventional one consisting of an r-f transformer, a variable tuning condenser and a trimmer condenser. The transformers are used as coupling devices to introduce the signal voltages to the input, or grids of the tubes in the case of the secondaries and to receive the output, or plate current in the case of the primaries. The primary of the first r-f transformer, of course, obtains its signal energy directly from the antenna to which it is connected. The output or plate circuits of the tubes carry a fluctuating current which is composed of a high frequency, or alternating current component and a direct current component. This output current possesses all of the characteristics of the signal wave which are represented by a-c voltages fed to the grids. The output is greatly increased in amplitude over the input, the extent of the increase or gain in signal strength per stage being determined for one thing upon the tube's own amplifying properties, and for another on the external circuit design.

An important point to remember in regard to the proper connection of the secondary of a transformer to the grid of a tube is to always use the lead coming from the last turn on the "outside" of the secondary. By "outside" we mean the end of the secondary which is farthest from that portion of the coil where the primary is usually mounted. The last turn, on the opposite end of the secondary, or the end which is located nearest the primary, is called the "inside," and the connection made from here usually goes to

the ground. The "outside" end of the primary goes to the plate and the "inside" to the voltage supply. In the case of the 1st, or input transformer the "outside" end goes to the antenna and the opposite end to the ground. These connections are not so easy to follow in the case of the 2nd and 3rd transformers of the screen-grid set because of the slight difference in size between the primary and secondary. Although these connections are already made with fine wires soldered to the terminals you should examine them.

The variable tuning condensers are used to resonate the r-f circuits to a particular station's frequency, the one we desire to listen to, while the function of the trimmer condensers, which are easily adjusted by means of a screw, is to allow for making small changes in the capacitance of each r-f circuit in order that the individual stages may be placed in exact resonance with one another. It might be mentioned that trimmer condensers, also called line-up condensers, are a valuable adjunct to a modern radio receiver as they compensate for slight variations in the tuning circuits which may be caused by wiring or discrepancies in coils or condensers when manufactured in large quantities.

The antenna system is designed to accommodate either a long or short antenna by a simple change in connection to either one of two antenna terminals provided for this purpose. If a short antenna is used it should be connected directly to the r-f coil, but with a long antenna the lead-in wire should be connected to the position which places a small .00025 mfd. condenser in series with the coil. The "LOCAL-DISTANT" switch should be used if strong local signals are picked up which would tend to cause detector overloading. By closing the switch, as shown in the diagram, the amount of signal energy transferred from the primary coil to the secondary is reduced and, thereafter, the desired signal level can be regulated by manipulating the volume control.

How Screen-Grid Voltage is Obtained and Regulated. The circuit that supplies positive voltage to the screen grids operates according to the principles as explained by Ohm's Law which states that a certain relation exists between current, resistance and voltage. The resistor of 6000 ohms is really a potentiometer with a movable arm. It is supplied with d-c voltage from the power supply circuit through a 40,000 ohm resistor connected in series. Observe how the resistors are placed in series and in turn connected across the d-c power supply. Suppose there is 300 volts across the two resistors in series, then from this we subtract a certain voltage drop due to the 40,000 ohms, which let us say is 260 volts, then we get a remainder of 40 volts which is applied across the 6000 ohms. Hence, any voltage between zero and 40 may be obtained from the 40,000 ohms as determined by the amount of resistance included between the lower, or grounded end of the wire and the point where the contact arm rests.

Negative grid bias for the screen-grid tubes is furnished by the d-c plate current of these amplifiers returning to the cathodes of the tubes through a fixed resistor of the proper value, or 400 ohms for this circuit. Positive plate voltage for the screen-grid tubes, UY-224's, is supplied through an 8000 ohm resistor inserted in series with the positive end of the d-c output of the power pack. The function of the r-f chokes in the plates of the radio amplifiers is to block the r-f component of the plate current and keep it out of the power supply circuit and the purpose of the 0.1 mfd. by-pass condensers connected between the respective chokes and the cathodes of the tubes is to furnish an easy path, or one of low reactance, to this r-f

component. A 0.1 mfd. by-pass condenser is shunted around the 400 ohm grid bias resistor to permit the r-f signal currents to pass through and thus prevent serious losses which would surely occur if this energy was forced to take a route through the resistor. The main purpose behind this design is to provide a radio-frequency circuit in which the signal current will circulate with highest efficiency to be impressed as an alternating voltage between the control grid and cathode of the tube.

THE UY-224 A-C SCREEN-GRID TUBE AND THE UY-227 A-C TUBE

The UY-224 tube consists of four electrodes, namely: a plate, a control grid, a screen grid and the cathode with a-c heater. A four-electrode tube is known as a "tetrode."

The UY-227 tube has only three electrodes, namely: a plate, a control grid and the cathode and heater unit. A three-electrode tube is given the name "triode."

Reference should be made to Figures 2A and 2B which clearly show the construction of these tubes. Both tubes have a cathode and heater which are

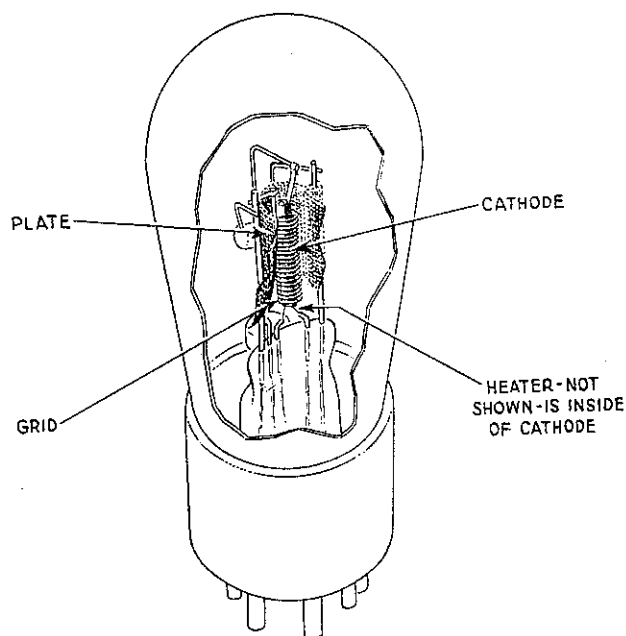


Figure 2A

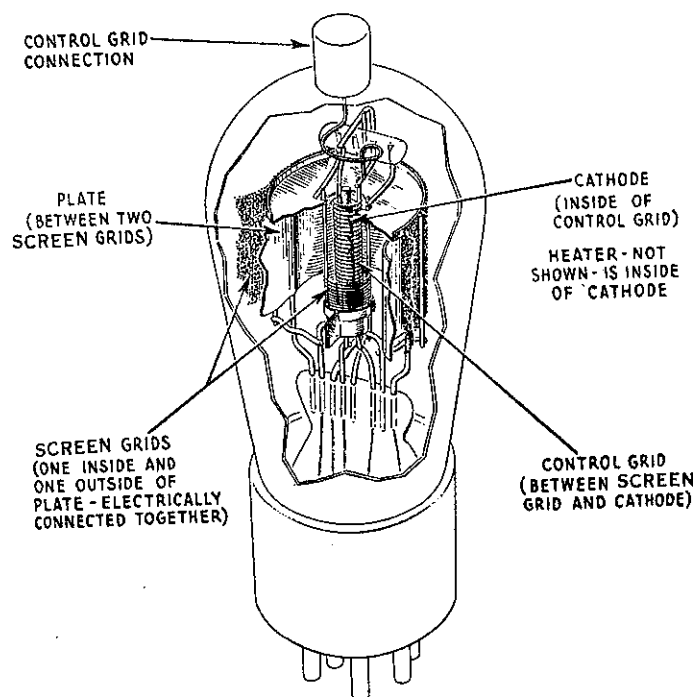


Figure 2B

quite similar physically, thus making it possible for some manufacturers to utilize these parts interchangeably in the construction of their tubes. A small wire, called the heater, is imbedded inside of a special insulating material which is cylindrically shaped and around which is placed a metallic thimble, or sheath, previously covered with an oxide coating. It is this metal sheath of oxide, of "cathode," which gives off electrons when the small heater wire is raised in temperature by the alternating current passing through it. The alternating current of proper voltage is obtained from one of the windings on the power transformer. Thus we see that the

heater wire, which cannot be shown in the illustration because it is encased in the insulator, serves only to conduct the current and indirectly heat the electron emitting oxide material, or cathode. Remember, the coated cathode around the insulator in the UY type tube is the source of electron emission. It will be recalled that the source of electrons in the UY type tube, such as the 245 or 201-A, is the hot filament wire itself, the filament wire in the UX tubes being treated with an oxide similar to the coating on the metal thimble in the heater type (or UY type) tube.

The UY-224 screen-grid tube is equipped with 5 pins in the base and a metal cap located on the top of the glass envelope, the control grid being connected to this cap. A point to be mentioned in regard to the sockets used with these tubes is that the heater terminals in some sockets are marked "H, H" and in others "FIL." The plate and cathode pins are in the same positions in the bases of both the 227 and 224, but the screen grid of the 224 connects to the pin which in the 227 would make connection to the regular control grid.

The screen grid is made up in two separate parts which are connected together electrically. One part of the screen, in the form of a spiral coil, is placed between the plate and the control grid, this being called the "inner screen." The other part, in the form of a metal screen of meshlike construction, is located outside of the plate, this part being known as the "outer screen." There is a thin metal cover mounted over the outer screen which acts as an electrostatic shield between the plate and the control grid lead which goes to the metal cap on the top of the tube.

The internal capacity between grid (control grid) and plate of the UY-224 is greatly reduced by the presence of the screen (screen grid) to a value which may be considered negligible. This arrangement effectively shields the control grid from effects caused by plate voltage variations through the inter-element capacity (grid to plate). If allowed to exist this capacity would permit troublesome feedback of r-f energy from the plate to grid circuits with the result that unwanted oscillations would be set up in the circuits. Due to the open spiral coil construction of the inner screen grid and the lower positive potential applied to it in comparison to the higher positive potential on the plate accounts for the fact that the electron stream is not obstructed as it passes through the vacuous space in the tube from cathode to plate. However, if an exceedingly high positive potential on the screen is permitted it would cause the screen to act like a miniature plate with the result that electrons would be prevented from going through to the plate. The latter situation must not prevail because it would reduce the effectiveness of the tube as an amplifier, as it would naturally lessen the current flow in the plate circuit.

The screen-grid tube fulfills two important functions: First, it practically eliminates inter-element capacity and thus makes the use of external neutralizing, or stabilizing devices unnecessary. Second, it provides an unusually high degree of radio amplification, or signal gain per stage. The high amplification makes it necessary to provide shielding between the r-f coils and, also, further shielding on the control grid leads to prevent external capacitative coupling between the grid and plate circuits.

The comparative qualities of the UY-224 and UY-227, the latter tube being a popular type for radio-frequency amplification in many receivers, can be realized by inspecting the following tables:

	<u>UY-227</u>	<u>UY-224</u>
Heater Voltage	2.5 volts	2.5 volts
Heater Current	1.75 amperes	1.75 amperes
Plate Voltage	+ 180 volts	+ 180 volts
Plate Current	6 milliamperes	4 milliamperes
Grid Bias Voltage	-13.5 volts	-1.5 volts
Amplification Constant	9	420
Mutual Conductance	1000 micromhos	1050 micromhos
Plate Resistance	9000 ohms	400,000 ohms
Grid to Plate Capacity	3.3 micromicrofarads	0.01 micromicrofarads

From the tables we see that the heater voltage and current for both tubes are identical. The plate voltage of both tubes is also the same and the mutual conductance nearly alike. However, in the case of the UY-224 we find that the grid bias voltage is much lower, the amplification factor enormously greater and the plate resistance considerably higher when compared to the UY-227. We have analyzed the comparative qualities of these tubes and other features pertaining to the r-f circuits in the following eight topics and with reasons for advantages which one tube has over the other.

1. The heater voltage of the UY-224 is the same as that of the UY-227 and, therefore, a common winding on the power transformer may be used to supply heater current for tubes of both types when used in the same receiver. This is a distinct advantage in simplifying transformer construction.
2. The plate voltage and current requirements of both tubes are moderate, therefore, the use of a UX-280 rectifier will prove ample for supplying all plate voltages.
3. The grid bias of the UY-224 is lower than that required for the UY-227. A low grid bias allows a tube to respond effectively to a low input voltage, hence, giving maximum output, but the disadvantage here is that a large grid swing will cause overloading.
4. The amplification factor of the UY-224 is considerably higher than for the UY-227. In practice it is impossible to get the full amplification constant from these tubes. However, the amplification obtainable from the UY-224 in a well-designed stage is several times greater than from the UY-227. A fair idea of the greater r-f gain possible from the screen-grid tube may be had by estimating that the average radio circuit employing a three-electrode tube, for instance the 227 type, has a gain per stage of approximately 8, whereas, when a four-electrode or screen-grid tube is worked in a similar circuit, but designed expressly for the latter tube, the gain in signal level possible is from 30 to 40 per stage. So it is safe to assume that a UY-224 tube is about four or five times more effective as an amplifier. Placing the control grid close to the cathode and relatively far from the plate increases the amplification factor enormously while the insertion of the screen-grid increases the plate resistance. The advantages of high plate resistance are obtained from this tube without

sacrificing the additional advantages of high mutual conductance. Since the distance between the grid and cathode is much less than the distance between plate and cathode then a positive potential impressed on the screen grid will cause the flow of plate current to be accelerated. In fact, the screen grid (because of its position in the tube) produces a greater acceleration of plate current than does the higher voltage impressed on the plate. The mechanical construction of the screen does not permit it to collect many of the electrons which would ordinarily go to the plate, hence, the majority of electrons which constitute the tube current pass on through the screen grid to the plate; only a limited quantity flow in the screen-grid circuits as direct current.

5. The mutual conductance is slightly lower in the UY-227 than in the UY-224. Mutual conductance is a direct function of amplification constant and plate resistance, and is a measure of a tube's general performance. However, the mutual conductance of an r-f amplifier does not assume the importance that it does in other stages. Considering the amplification constant of the UY-224 its mutual conductance is very high. The positive potential on the screen grid in relation to the cathode is necessary for operation as the mutual conductance of the tube is a direct function of the value of this voltage. Therefore, it follows that with a very low voltage the mutual conductance will be low and with maximum voltage the mutual conductance will be maximum. Consequently, if we vary this voltage we can easily control the sensitivity of the r-f amplifier and this will act as a volume control for the receiver. In practice this screen-grid voltage is varied from 0 volts at minimum volume to about 40 volts positive, or more at maximum volume.

6. The plate resistance of the UY-224 is many times greater than for the UY-227. For the different broadcast frequencies that are used in operation it is known that the resistance of the load circuit into which the tube works should be as great, or greater than the impedance of the tube. On this account the 224 tube requires an output circuit different from that used with other tubes, such as the 227 for example. This point was brought out in a foregoing section. In practice the high resistance is gained by concentrated inductance in the coil windings. Another important advantage of high plate resistance is improved selectivity. This is accounted for by the reduced r-f resistance in the adjacent grid circuits. In a radio-frequency circuit the plate resistance reflects inversely in the adjoining grid circuit.

7. Because of the fact that the self-capacity of the UY-224 is practically negligible the r-f circuits can be constructed without stabilizing, or neutralizing devices of any kind providing, of course, all circuits external to this tube are properly shielded, as previously mentioned. The low internal capacity of the tube is accomplished through the insertion of the screen grid between the control grid and the plate. The values in the tables show that grid-plate capacity is .01 mmf. for the UY-224 and 3.3 mmf. for the UY-227, thus indicating that self-capacity is lowered about 1/300th through the use of the screen grid. Again refer to Figure 2B which shows the screen grid construction in the 224, and its absence in the 227 in Figure 2A.

8. High amplification gain is an advantage because it permits the use of a single stage of resistance coupling in the audio amplifier followed by a

final stage which is usually transformer coupled. It is generally agreed that resistance coupling gives pleasing and very satisfactory reproduction.

FACTORS WHICH GOVERN A SCREEN-GRID RADIO-FREQUENCY SYSTEM

Now let us finish our discussion of PART 1 by summarizing the important factors concerning screen-grid amplifiers. Although one or more of the items may have been mentioned earlier in the lesson they will bear repetition. Important facts relating to grid swing of the radio amplifiers and grid biases are also explained.

(a) Each r-f stage must be shielded in order to prevent oscillation due to plate to grid feedback of r-f energy through wiring, or coils. This shielding should extend over the coils and the control grid leads but not necessarily over the tuning condensers and tubes as the radio-frequency field surrounding such parts is not particularly strong.

(b) The primary of each r-f transformer should have an inductance as high as possible to approach the output impedance of the 224. The primary of a transformer designed for use with a tube of some other type than the 224 does not require such a high value of inductance. For the radio circuits we are considering, as in Figure 1, a high external plate or load impedance is essential, as otherwise the amplification gain of each stage will be low. Figure 3 is a cut-away view of a typical r-f transformer wound to give high impedance. Note the large number of primary turns.

(c) A power unit must provide suitable a-c voltages for the heaters of the 224 and 227 tubes. This voltage is 2.5 volts with a current requirement of 1.75 amperes for each tube used. Also, direct current which has been properly filtered, or smoothed out, must be provided for supplying the control grid with about 1.5 volts negative bias, and the screen grid with about 40 volts positive potential, and the plate with positive 180 volts. This power unit also supplies the detector and audio stages with operating voltages at specified values.

(d) Due to the high sensitivity of the screen-grid circuits it is desirable to reduce the amount of signal energy when receiving strong local broadcast programs. In certain circuits this is accomplished by disconnecting the antenna from the input r-f coil by means of a switch, called "LOCAL-DISTANT" switch. If this method is used the 1st r-f transformer is not shielded and usually a small fixed condenser (for example, one with a capacitance of .00023 mmf. is used in certain circuits) is automatically shunted across the antenna coil by the switch. Shunting the condenser around the transformer primary provides an oscillatory circuit on which the signal energy may be picked up. Another type functions when the switch is on the "LOCAL" position to connect the antenna through a small resistor to ground, the value of the resistor being of the order of 15 ohms. The purpose of this switch, as heretofore explained, is to prevent the strong carrier of a local station from overloading the detector, thereby causing distortion.

(e) Radio-frequency by-pass condensers and r-f chokes, called filter inductors, are necessary to prevent the r-f energy in each stage from entering another stage through the common power supply leads. These condensers

voltage depending upon the current strength and the number of ohms of resistance. Actually this resistor is connected in series between cathode and ground, and we also find that the grid return lead of the tube is connected to ground, the grid circuit being completed through the secondary of the r-f transformer. By this arrangement the flow of plate current through the grid bias resistor causes the cathode to become positive in potential with respect to the grid, or expressed the other way around and meaning exactly the same thing, the grid is made negative with respect to the cathode, which is the reference point of all potentials of the tube.

(g) Let us now discuss the relation of positive grid swing from a signal voltage to the amount of permanent bias supplied to the control grid of the 224. If your radio set is located close to a broadcasting station the signal might come in so strong that the radio-frequency voltage applied to the control grid of the tube would cause the grid potential to actually swing over and become positive with respect to the cathode. You can well imagine from your previous knowledge of the control action which the grid exercises over the stream of negative electrons in the tube what the resulting effect would be if the grid ever assumes a positive electric charge. Supposing that this happened then the grid would naturally act in a manner similar to a miniature plate and, hence, attract electrons in great numbers. Since the flow of electrons between cathode and grid is nothing more than what we call grid current then the presence of this grid current makes the intervening space between cathode and grid act as though a high resistance were connected between these electrodes. In actual effect this is like placing a high resistance across the tuned r-f circuit, inasmuch as this circuit is always connected across the grid and cathode of an amplifier tube.

Therefore, it should now be clear that if an r-f amplifier grid were not supplied with a permanent negative bias, or if the bias were so low as to be overpowered by strong positive impulses from a local signal, the space between these two elements would exhibit all of the characteristics of a high resistance shunted across the r-f tuned circuit. This condition is undesirable. What we would like to have is a grid which never becomes positive but is always working at greater or lesser negative values with respect to the cathode. The condition should be such that the grid to cathode path remains at all times practically like a small condenser, the electrodes acting as plates and the space as the dielectric. If this is fulfilled in practice the grid is left free to act efficiently as an electrically charged body whose potential is constantly varying in accordance with the characteristics of the signal wave, and the changing grid potential will cause a corresponding variation in plate current. We know this to be the case because the control of plate current is due to the effect which the electrically charged grid has over the electron stream as it moves through the vacuous path in the tube from cathode to plate.

What we have just said in regard to the radio-frequency grid swing has some bearing on the tuning qualities of the receiver referred to as "Broadness, or Sharpness" of tuning. The introduction of even a small amount of resistance in a circuit of this kind causes the resonance curve to become less sharp or peaked, or to flatten out as it were. This results in what is known as "broad tuning." In other words the receiver then cannot discriminate between broadcast frequencies when they are 10 kilocycles apart, but

will respond with almost equal sensitiveness to the frequencies of more than one station, thus causing serious interference.

This extreme sensitivity of the control grid of the 224 is responsible for the easy manner in which remote and distant stations are brought in on a modern screen-grid receiver. Moreover, it has the distinct advantage of permitting the use of shorter antennas than have heretofore been required to pick up signals from distant stations. An antenna not exceeding 50 feet in length usually gives the best results.

PART 2

THE DETECTOR

The detector circuit in our receiver employs a UY-227 heater-type tube. Reference to the diagram in Figure 1 shows that an incoming signal passes through two stages of screen-grid amplification before it reaches the detector grid. Now in regard to the detector let us explain that there are two types of detectors in common use today, either one of which gives satisfactory results when properly operated. The detectors are classified according to their action and are known as the power, or grid-bias type, and the grid leak-condenser type. The latter type is used in the receiver you will construct, the detector action being controlled by a grid-leak resistance of the order of 2 megohms placed in parallel with a small fixed condenser of .00025 mfd. capacitance, and these units in turn being connected in series with the grid circuit. The arrangement is shown in Figure 6.

The relative characteristics of both methods of detection will now be pointed out. One advantage of the power detector is that it may be operated at a high plate voltage which gives it sufficient output to drive a power amplifier tube without the need of an intermediate stage of audio amplification.

To off-set this advantage the power detector has several noticeable disadvantages as follows: First, a good strong signal is necessary to operate the power detector satisfactorily and this often requires the use of several stages of radio-frequency amplification. Second, it is not sensitive to weak signals and, moreover, it will give little or no output on signals having a low percentage of modulation.

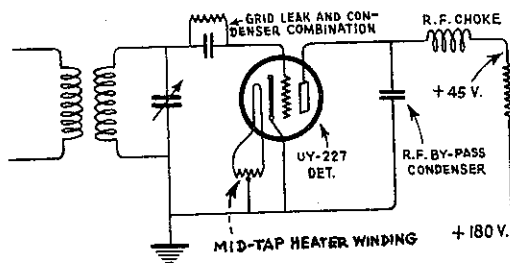
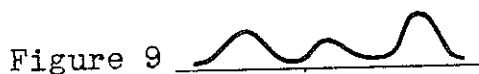


Figure 6

The characteristic of the grid leak-condenser type are about the reverse of those of the power detector. The grid leak-condenser type possesses the following advantages: First, it is very sensitive to a very weak signal. Second, it is responsive to signals having a low percentage of modulation.

ACTION OF THE DETECTOR. An incoming signal wave that is intercepted by the antenna of a radio receiver induces a current in the antenna circuit which has the same characteristics as the wave sent out by the transmitter antenna. The current is a high-frequency alternating current, the frequency being determined by the constants of the transmitting station's r-f circuits. Suppose, for example, the transmitter is oscillating at a frequency of 1,000 kilocycles and the microphone is being used, then this high-frequency current will have superimposed upon it another frequency of a lower order which represents the modulating frequency. The latter frequency covers a band of between approximately 60 and 7,000 cycles, which for all practical purposes is sufficient to represent the voice, or musical tones originating at the microphone. However, in practice, the frequencies of broadcast stations in certain zones are separated by 10,000 cycles for a complete coverage of the audio band. Figure 7 shows a graphical representation of a modulated high-frequency current. Now the purpose of the detector is to demodulate this signal energy so that only the music, or voice frequencies remain to be passed along to the audio system to be amplified and then applied to the loudspeaker. (Demodulate means to separate the a-f from the r-f.)

The circuit as arranged in Figure 6 does not provide the detector grid with a negative bias because the grid return lead goes direct to the cathode. Since the grid is not supplied with bias voltage from the circuits a small electronic flow passes through the tube from the cathode to the grid and then from the grid through the leak resistor and secondary of the r-f transformer and back to the cathode. This electron current circulating through the grid circuit, as just traced out, is quite small due to the limiting action of the grid leak. Its high resistance holds back a certain quantity of electrons and thus retards the flow. When a signal is tuned in there is a high-frequency current in the grid tuned circuit and this energy passes readily through the path furnished by the condenser and in this manner the signal voltages are applied to the grid.



The action taking place is as follows: On the positive alternation of a signal current the grid will tend to draw more current, but due to the IR drop, or voltage drop, an increase of current through the grid leak will cause the current to remain substantially the same. On the negative alternation, however, the grid current will be either reduced, or it will stop flowing because the grid leak resistor has no limiting action on a decreasing amount of current. Thus, our grid current assumes a characteristic as shown by the curves in Figure 8. It is to be understood that every variation of grid voltage is repeated by changes in the value of the plate current and, consequently, we have a condition existing in the plate circuit

where these half-frequency variations are at radio-frequencies but the effective plate current, or the one which carries only the voice or musical frequencies, is simply the average value as shown in Figure 9. The average value is the audio component and the one that is used to drive the loudspeaker to give the original reproduction at the microphone. Or, in other words, the average value of the plate current corresponds to the modulating frequency of the signal wave. The modulating frequency is also called the "audio" and sometimes the "low-frequency" component. The r-f current is the "carrier" frequency, or the one on which transmission of the signal is accomplished through space. The modulating frequency after being separated in this manner from the r-f, or carrier, is then passed on to be amplified by means of the audio stages to the desired level for our loudspeaker, as already mentioned. Remember the term "demodulate."

Since it is undesirable to permit the r-f to pass beyond the detector output, or to the audio circuits, it is by-passed through a filter placed in the detector plate circuit as indicated on the diagram. This filter consists of an r-f choke and a condenser of .01 mfd. capacitance, the choke serving to block the passage of the r-f and the condenser serving as a path for it to flow through to the ground and thus dissipate this energy.

The plate circuit is completed through a resistor of 40,000 ohms which together with a .01 mfd. condenser acts to couple the detector output to the grid of the 1st audio amplifier. From the lower end of the resistor the plate circuit goes to the +B supply, or positive side of the d-c power supply.

PART 3

THE AUDIO AMPLIFIER

The schematic diagram in Figure 10 shows a typical audio system with the output of the detector feeding into a resistance coupled stage of audio amplification and this stage coupled to two power amplifiers operating in push-pull relation. Points of similarity between this circuit and the one given in Figure 1 can be easily recognized. A satisfactory level of output for properly driving a loudspeaker can be obtained through the use of the two audio stages when grid leak-condenser method of detection is employed. In these amplifier circuits the last stage being of the push-pull type, as just stated, utilizes two tubes of similar kind which about doubles the wattage output over that obtainable when only one tube of a similar type is used.

Examining the diagram in Figure 10 we see that the output of the UY-227 detector tube is coupled by means of resistance coupling to the input of another UY-227, the latter being used as a first audio-amplifier tube. Resistance coupling does not give any step-up gain of the signal strength other than that obtained through the normal action of the tube, due to its amplification factor. However, this fact is offset by the exceptionally good quality of output with this type of coupling. The resistor coupling consists of a detector plate resistor of 40,000 ohms, a condenser of .01 mfd. capacitance and a grid resistor for the 1st audio tube, the resistor being rated at 250,000 ohms. When the audio current from the detector output fluctuates as it passes through the 40,000 ohms resistor the current

generates an audio-frequency voltage across the terminals of the resistor, and this voltage feeds through the .01 mfd. coupling condenser to the grid of the amplifier. The condenser is large sized to permit the audio frequencies to flow through readily, this being necessary to insure good fidelity of reproduction from the loudspeaker.

The 227 audio-amplifier grid circuit consists of a grid resistor of 250,000 ohms, which has been referred to previously, and which controls the flow of electrons collected by the grid, that is, it controls the flow of grid current. The negative bias for this grid is obtained through a 1000 ohm resistor, inserted between the cathode and ground, since the plate current flowing through the resistor causes the cathode to assume a certain positive potential with respect to the ground, or it may be said that the ground is at a certain negative potential to the cathode. It follows, therefore, that the grid also being connected to ground through the resistor will place the grid at the proper negative voltage with respect to

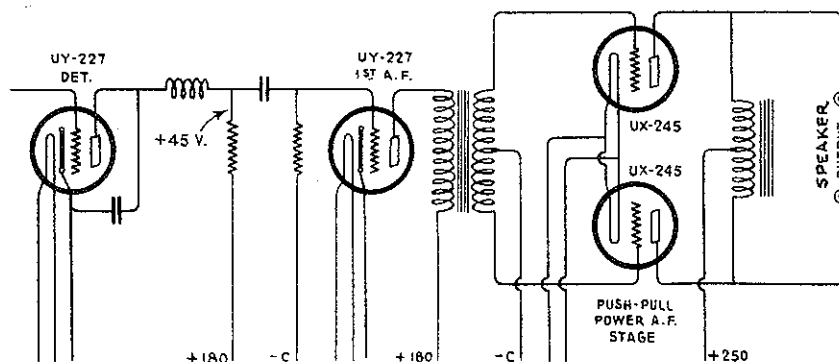


Figure 10

the cathode. Figure 11 shows fundamentally the entire arrangement for coupling by the resistance method between a detector and first audio tube, and how the voltages could be supplied by means of batteries instead of a power unit, as in an electric set.

The 1st A-F Amplifier. The UY-227 tube used as a first a-f amplifier has an amplification factor of approximately 9, which value we are practically able to take full advantage of in this stage. An a-f transformer is included in the plate circuit of this tube, the transformer being different from the conventional a-f transformer in that its secondary has a center tap. This is clearly shown in Figure 10. The splitting of the secondary into two sections is necessary in order that the signal output of the secondary can be made to work into two tubes in push-pull relation. A transformer of this type is known as a push-pull input transformer. It has,

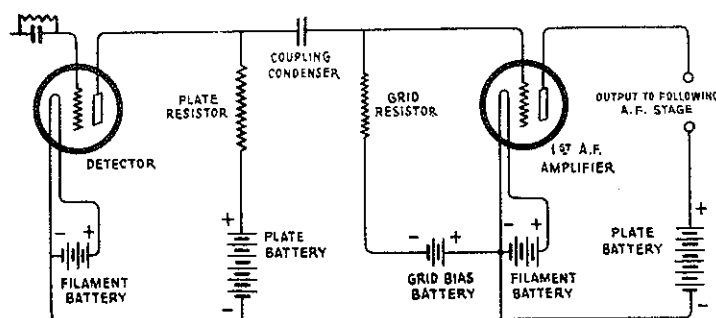


Figure 11

in this case, a step-up ratio (between the primary and each half of the secondary) of approximately 1 to 3. The center tap is the common return for each grid circuit and the tubes receive their negative bias through this connection.

How Tubes in Push-Pull Operate. The diagram in Figure 12 illustrates one type of push-pull circuit and it is drawn in simplified form which makes it easy to see this relation of the parts and how the voltages are applied. It is seen that the primary of the input stage connects to the plate terminal of the 1st a-f tube. In this primary flows the fluctuating audio-frequency current which induces an a-c voltage of similar characteristics in the split secondary and from this point the a-f energy is carried to the grids of the two tubes in push-pull through the connecting leads

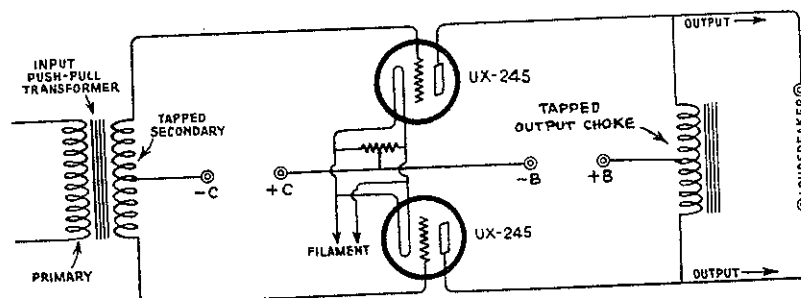


Figure 12

attached to the extreme ends of the secondary winding. At any instant the grids are at opposite voltage polarities, which means that when one grid is positive the other is negative. This action causes an increase in the plate current in one tube and a decrease in plate current in the other, with the final result that we get a much greater change in total plate current than if only one tube were used for this purpose. The low impedance of the 245 tubes permits this circuit to work into an ordinary magnetic type loudspeaker with only a tapped choke inserted in the plate for coupling purposes. The tap is the common connection through which the +B voltage is delivered to the plates. The a-c or audio component of the plate current may be obtained by connecting the terminals of the loudspeaker from plate to plate of the two tubes. This is shown in Figure 12. If a dynamic type loudspeaker is used it will be necessary to employ an impedance adjusting transformer between the output of the two plates and the cone coil, or voice coil, of the dynamic speaker. This is necessary because the a-c impedance of cone coils at voice frequencies is less than 100 ohms. Transformer coupling in the output of the push-pull power amplifier may also be used, as shown in our schematic diagram in Figure 1.

THE UX-245 POWER-AMPLIFIER TUBE.

The characteristics of this type tube make it desirable for use in a push-pull audio amplifier. It is to be kept in mind that in a push-pull amplifier the performance of two power tubes used should match each other as near as possible so that the tubes will do their work with equal effectiveness. Matching tubes in this way might be called a disadvantage.

Characteristics of the UX-245 Power Tube:

Filament Voltage	2.5 volts
Filament Current	1.5 amperes
Plate Voltage	+ 250 volts
Plate Current	32 milliamperes
Grid Bias Voltage	-50 volts
Amplification Factor	3.5
Plate Resistance	1900 ohms
Undistorted Output	1600 milliwatts

The outstanding advantage of the UX-245 tube is its large undistorted output with a low plate voltage. The requirements of this tube permits the UX-280 to be used as a full-wave rectifier. Another desirable feature of the 245 is its low plate resistance. A low resistance output tube allows better quality of output which is especially noticeable at the lower frequencies. The undistorted output of a 245 is slightly greater than in the case of the 210 type, and about one-third that of the 250 type. About 3 watts output can be obtained from two UX-245 tubes which is an output that will produce more volume than is actually required in the average home. A reserve of power is always to be desired, even though one may never expect to use it, because reserve power contributes to the quality of output at any volume.

PART 4

THE POWER SUPPLY CIRCUITS. A-C INPUT AND POWER TRANSFORMER.

The power unit consists of a power transformer, a full-wave rectifier, a filter and a voltage divider system for supplying the proper d-c voltages to the tubes.

The power transformer is built with a primary and four secondaries all mounted on a heavy laminated iron core. The primary receives the 110 volt, 60 cycle a-c through the plug and the lamp cord, when it is connected to either a lamp socket, or wall outlet, and the operating switch is in the "ON" position. The a-c in the primary sets up an a-c voltage of similar frequency in each of the secondaries; the actual voltage in any winding depends mainly upon the number of turns with which it is wound. Three of the secondaries are low voltage windings used as follows: One supplies the filaments of the 245 tubes, another supplies the heaters of the 224 and 227 tubes, and the third serves the filament of the 280 rectifier. Two of the windings are mid-tapped, as shown in the diagram in Figure 1, with connections terminating at the ground for the purpose of preventing any a-c ripple being set up by these circuits. The fourth secondary winding is larger than the rest since it is required to furnish a high a-c voltage to the plates of the 280 tube. This winding has a mid-tap which is grounded and forms the negative side of the d-c circuit from the rectifier.

The filament winding of the 280 is also center tapped and the connection carried from this point to the input of the filter forms the positive side of the d-c circuit.

PART 5

THE RECTIFIER.

In the receiver under consideration the UX-280 is used as a full-wave rectifier. The plates of this tube are supplied with a-c from the power transformer and because of the one-way conductivity of a vacuum tube (the electron stream flows only from the filament to plate) this rectifier will deliver in a circuit connected to its output a pulsating direct current. After being smoothed out by means of a brute-force filter the output will flow as a substantially steady direct current suitable for supplying the plate and grid circuits of the tubes in the receiver proper. In short, this 280 tube provides direct current for the operation of an alternating-current receiver.

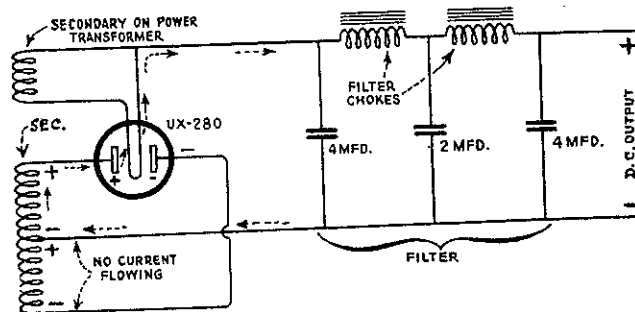


Figure 13

The theory of operation of the 280 in a typical circuit is as follows: Referring to Figure 13 we observe a rectifier circuit consisting of the 280 tube, a transformer capable of supplying the requisite plate voltage and filament voltage for this tube, two filter reactors or chokes, and three filter capacitors or condensers. In any thermionic tube there is a flow of current only when the anode, or plate, is at a positive potential in relation to the filament, or cathode. At negative plate potentials the tube offers infinitely high resistance to the flow of current which is accountable for by the repulsion which a negative plate will exert upon the negative electrons emitted by the filament. Now, examining this circuit will bring out the fact that alternating current flows in all of the transformer secondaries as the reversal of the positive (+) and negative (-) signs indicate when the primary is connected to the a-c line supply of proper rating, that is, 110 volts a-c at 60 cycles.

When the circuit is active the a-c flowing through the filament heats it to a temperature which causes electrons to be emitted. The electron flow is towards the plate which is charged to a positive potential at any particular instant, as we have just explained. While one of the plates is charged positive during an alternation of the a-c cycle the other plate will at that time be charged negative. It is easy to understand that the negative plate will repel the electrons and, therefore, no current will flow through this plate circuit of the tube but, on the other hand, the positive plate will attract electrons and current then will flow out of the tube into the positive side of the filter circuit. The path of the current is indicated by the arrows. In the latter case current flows only in the upper half of the secondary and not in the lower half. On the next

alternation the potential of the plates will be reversed, as indicated in Figure 14, and current will then flow in the other plate circuit through the lower half of the secondary and out to the filter circuit as shown by the arrows. By employing a circuit arrangement of this kind (that is, where each end of the plate winding of the transformer is connected to a plate with the center tap used as a common negative connection) we obtain a pulsation of direct current for every alternation of the alternating current. Before the rectified current is filtered it will have the characteristics somewhat as depicted by the second row of curves marked "R.A.C." meaning rectified a-c, as in Figure 15.

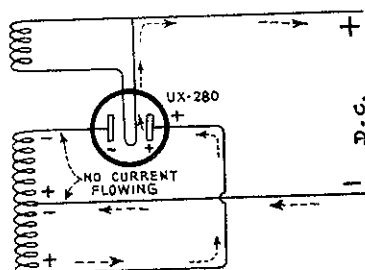


Figure 14

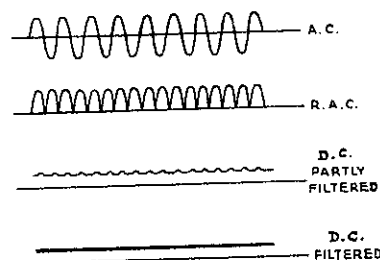


Figure 15

PART 6

THE FILTER

The filter consists of two inductors, or reactors, which are commonly called chokes, and three capacitors which are made to withstand a high d-c working voltage. The reactors, due to their high inductance, tend to oppose any variation in the strength of the current flowing through them. The current variations we refer to are the pulsations marked "R.A.C." in Figure 15. No impedance is offered, however, to the flow of a steady current, or pure direct current by the reactors; the only opposition in this case is that which is set up by the resistance of the windings. The latter resistance is called the direct-current resistance. The condensers act like reservoirs because they become charged, and periodically discharge, and in this way they supply voltage to the circuit which has the effect of filling in the gaps of the pulsations. After passing through the first reactor, or choke, the current is partly smoothed out, or filtered, and finally after emerging from the second choke it is practically the equivalent of a steady, or non-fluctuating d-c. The smooth character of the d-c output of the filter makes it suitable for supplying the plate and grid circuits of the receiving tubes. Figure 15 shows how the various filtering devices act upon the rectified current.

PART 7

THE VOLTAGE DISTRIBUTION SYSTEM

After the pulsating d-c from the 280 rectifier is completely filtered we have available for use a steady direct current of about 300 volts potential with a current capacity of 100 milliamperes. This voltage is of proper

value for the plate and grid circuits of the 245 power tubes, but for other tubes in the receiver this voltage is too high. It is to be understood that the grid does not receive such a high voltage as just mentioned, but that it obtains its bias from the d-c supplied by this high voltage by methods previously explained.

A means must be found for reducing the high voltage to values suitable for the 224 and 227 tubes. In practice we find two general methods of voltage distribution employed. They are commonly known as the parallel method and the series method.

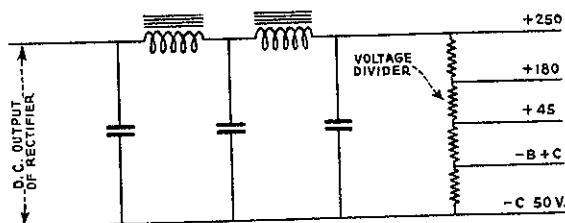


Figure 16

Where a high voltage is being supplied to the receiver the parallel method is most generally used. The reason for using this method is because the load is not so likely to be removed entirely from the rectifier circuit, but in the event that this did happen a very dangerous voltage would be generated. A typical circuit of a parallel system is shown in Figure 16. Notice how the taps are taken off at different points along the resistance. This resistance may consist of several separate units connected together, or just one tapped unit.

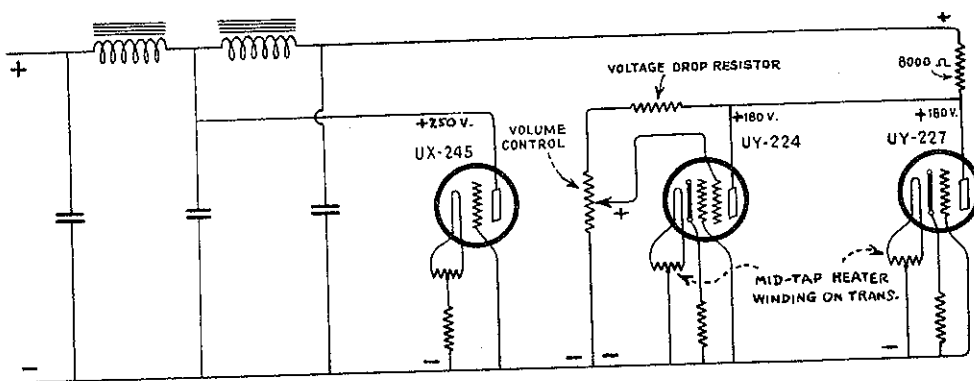


Figure 17

The series method, shown in Figure 17, is used in the screen-grid receiver that you will construct. The fundamental advantage of this method is in the fact that no current is consumed by the resistors which could be considered independent of the current drain of the tubes. The drain from the tubes is the entire drain put on the rectifier in this system. As the effectiveness of the condensers in the filter is inversely proportional to the total current flowing it is desirable to have the drain as low as possible.

Referring to both Figures 1 and 17 it is seen that the plate resistor of 8000 ohms drops the voltage from the high value of about 300 volts to 180 volts for the plates of the 224 and 227 tubes. The voltage for the 245's is taken direct from the output of the filter system. In Figure 1 the 40,000 ohm resistor in the detector plate drops the supply voltage from 180 to about 45 volts which is applied to the detector plate.

The actual construction of the screen-grid set will be taken up in our next lesson.

EXAMINATION - LESSON 32

1. What are the characteristics of screen-grid receivers that differ from those employing other type tubes?
2. In what three respects do the characteristics of a screen-grid tube differ from the usual heater-type detector amplifier tube?
3. Why do the r-f transformer primaries used in screen-grid receivers differ from those used in other type receivers?
4. Why are there no neutralizing condensers or stabilizing devices used in screen-grid receivers?
5. How is improved selectivity obtained in screen-grid receivers over those employing a similar number of tuned stages but using other types of tubes?
6. How does a grid leak and condenser cause a circuit to function as a detector?
7. Name the advantages of two types of detectors.
8. What are the advantages and disadvantages of push-pull amplification as used in a power audio stage?
9. Explain the principle of operation of the full-wave thermionic rectifier.
10. Why is a UX-280 tube sufficient for providing all d-c voltages used in the receiver discussed in this lesson?